CIMAC CASCADES 2017, Helsinki

Decrease NOx-emissions and Increase Efficiency:

Cylinder Cut-out in a Maritime Dual Fuel Engine

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HERCULES - 2

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Outline

- ☐ Motivation
- ☐ Description of the Modelling Approach
  - Development of Thermodynamic and Fluid Mechanic 1-D Engine Model
  - Optimization of Phenomenological Dual Fuel Combustion- and NO-model
- ☐ Cylinder Cut-out Operation
  - Engine Operation with Deactivated Cylinders
  - Effects on Efficiency and NO-emissions
- ☐ Conclusions

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Motivation

- Large dual fuel engines are a good alternative for maritime propulsion systems in Emission Control Areas to meet the emission legislation
- In part and low load, it can be assumed that cylinder deactivation leads to an improved efficiency and reduced NO-emissions
- Fuel expenses could be reduced and the environmental impact minimized
- Electronic cylinder cut-out can be realized without significant changes of the engine setup and can also be applied for retrofit

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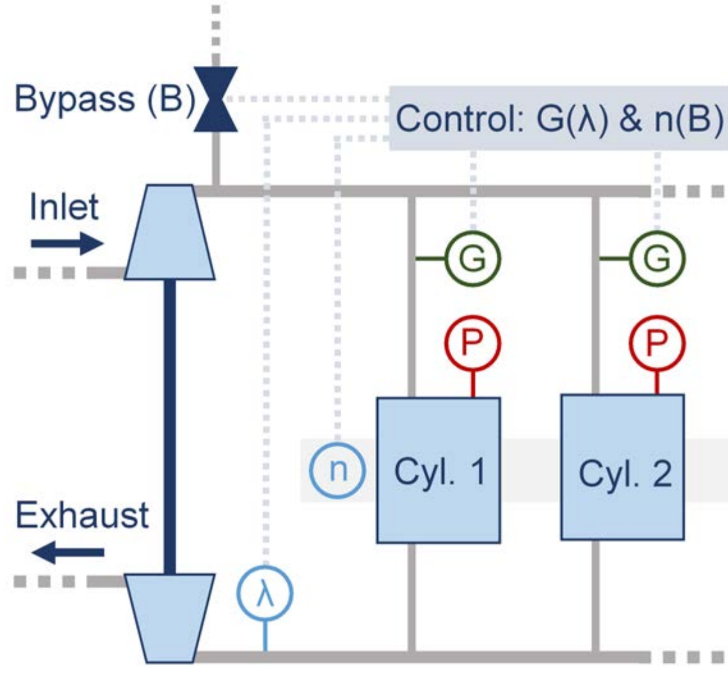
Description of the Modelling Approach

Development of Thermodynamic and Fluid Mechanic 1-D Engine Model

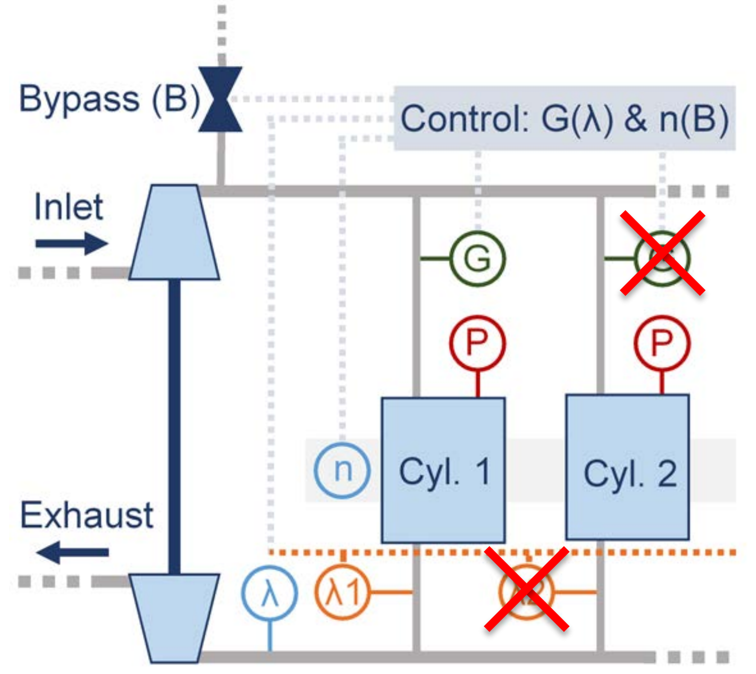
- Engine is modelled in GT-Power
- Turbocharged 4-stroke dual fuel engine with 7 cylinders in-line
- Gas injection upstream of the individual cylinders and direct pilot injection
- Equivalence ratio measured upstream of the turbine; applied to control the gas mass flow
- Prescribed torque is applied; charge air pressure and thus rotational speed are controlled by bypass valve

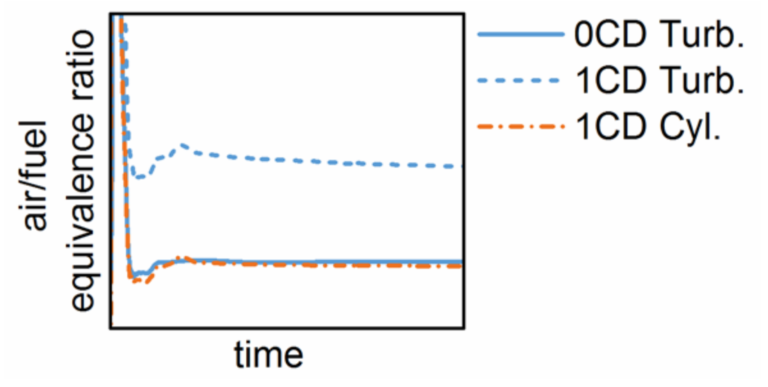


Description of the Modelling Approach

Development of Thermodynamic and Fluid Mechanic 1-D Engine Model

- ☐ Electronic cylinder cut-out: deactivation of gas injection upstream of cylinder
- ☐ Pilot injection is kept activated to prevent undesired scavenging of unburned fuel
- ☐ Due to cut-out cylinder, air is scavenged in exhaust manifold, thus global equivalence ratio does not represent fired cylinders
- ☐ Equivalence ratio of fired cylinders is applied for engine control



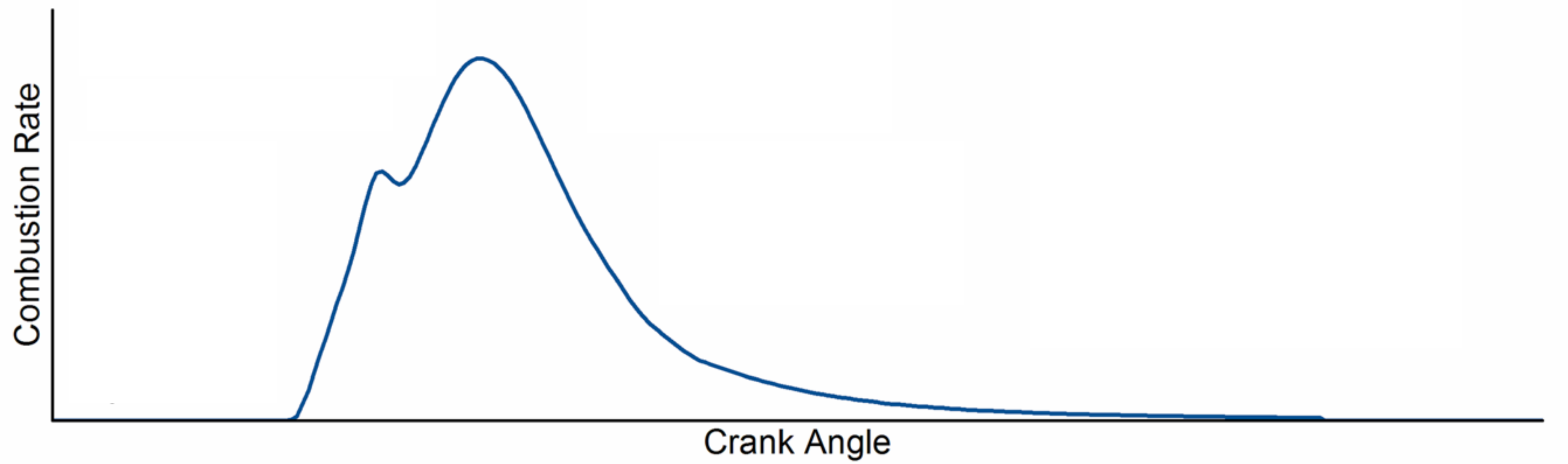


Description of the Modelling Approach

Development of Thermodynamic and Fluid Mechanic 1-D Engine Model

Dual fuel combustion:

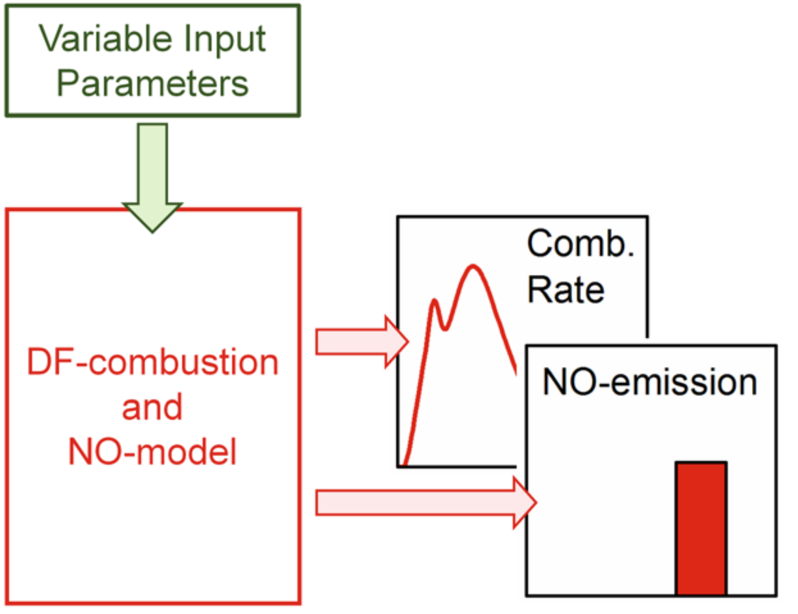
- ☐ Diesel auto ignites due to compression, its combustion ignites the natural gas
- ☐ Combines combustion properties of the compression and spark ignition engine
- ☐ Behavior depends on a variety of engine design and operation parameters



➡ Dual fuel combustion has to be represented by a suitable model

Phenomenological dual fuel combustion- and NO-model:

- Developed during the preceding project Hercules-C
- Predicts the crank angle dependent burn rates and corresponding NO-emissions
- 23 variable input parameters to adjust the model’s behavior

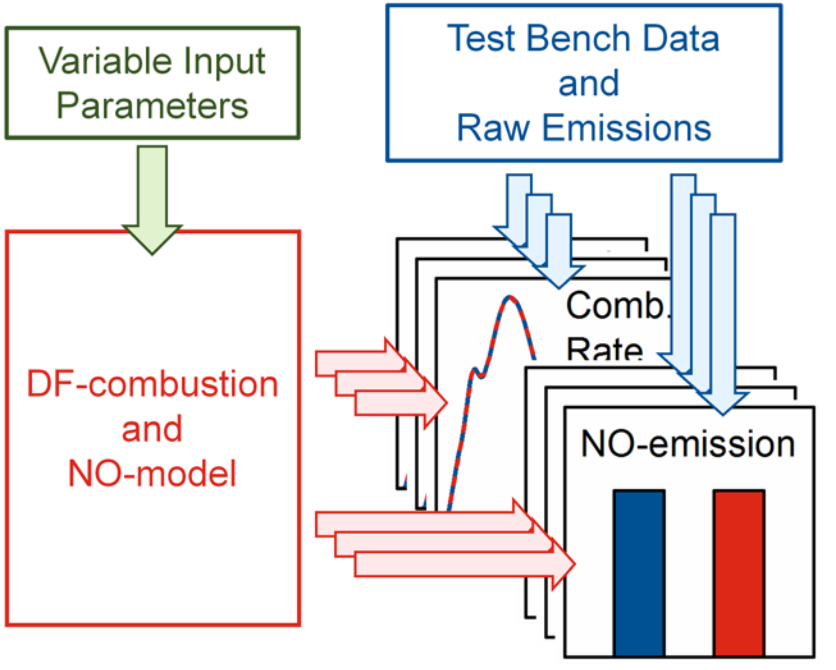


- Due to the very complex characteristic of the dual fuel combustion and NO-formation, the applied model is extremely sophisticated to handle

Description of the Modelling Approach

Optimization of Phenomenological Dual Fuel Combustion- and NO-Model

- ☐ Test bench results for static engine operation with varying:
  - Load
  - Equivalence ratio
  - Injection timing
- ☐ Input parameters need to be adjusted to represent the test bench measurements



- ☐ All engine operation points need to be represented by one set of parameters
- ☐ Optimization of these input parameters is a highly complex task

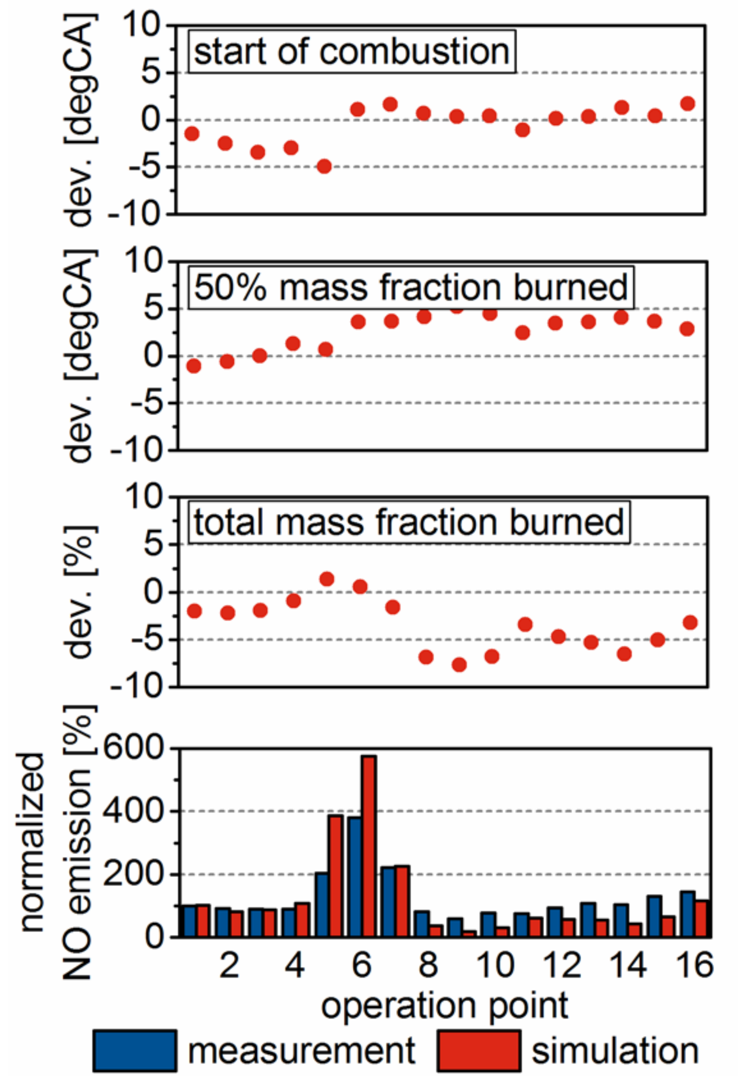
➡ **The numerical optimization software Optimus had to be applied**

Description of the Modelling Approach

Optimization of Phenomenological Dual Fuel Combustion- and NO-Model

Results of optimization work:

- ☐ Reproduction with good accuracy of:
  - Significant parameters of the burn rates
  - Fraction of fuel burned
  - NO-emissions

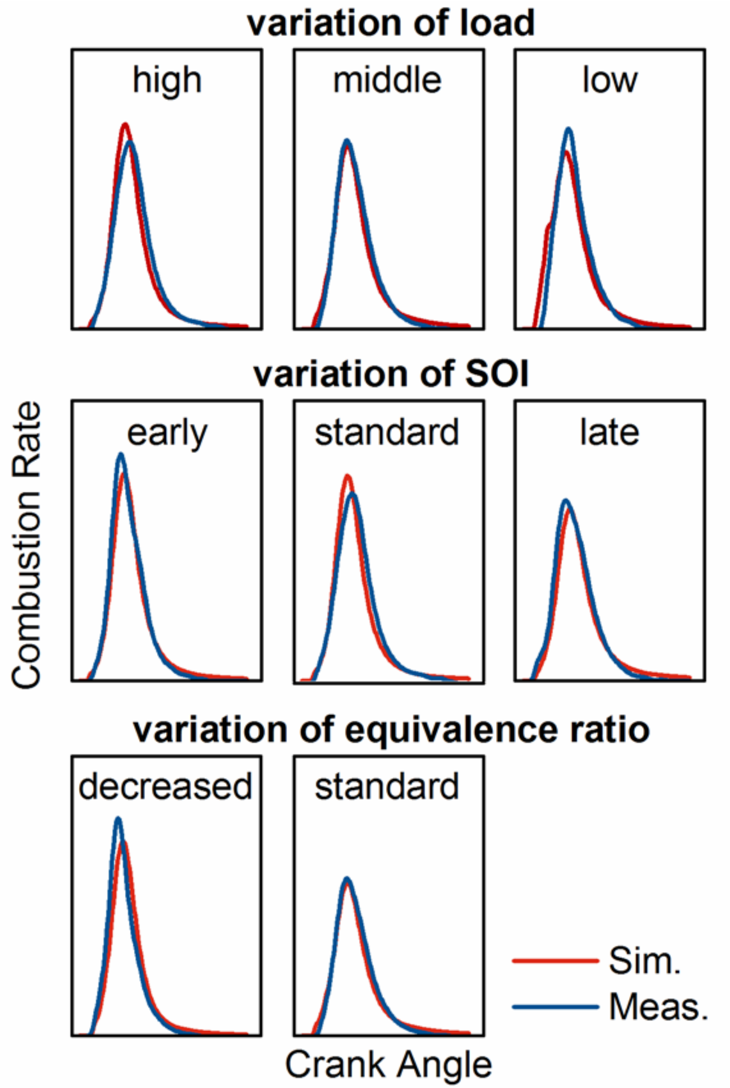


Description of the Modelling Approach

Optimization of Phenomenological Dual Fuel Combustion- and NO-Model

Results of optimization work:

- ☐ Reproduction with good accuracy of:
  - Significant parameters of the burn rates
  - Fraction of fuel burned
  - NO-emissions
- ☐ Optimized combustion rates fit good to the test bench results
- ☐ Good representation of the variation of:
  - Load
  - Equivalence ratio
  - Start of injection



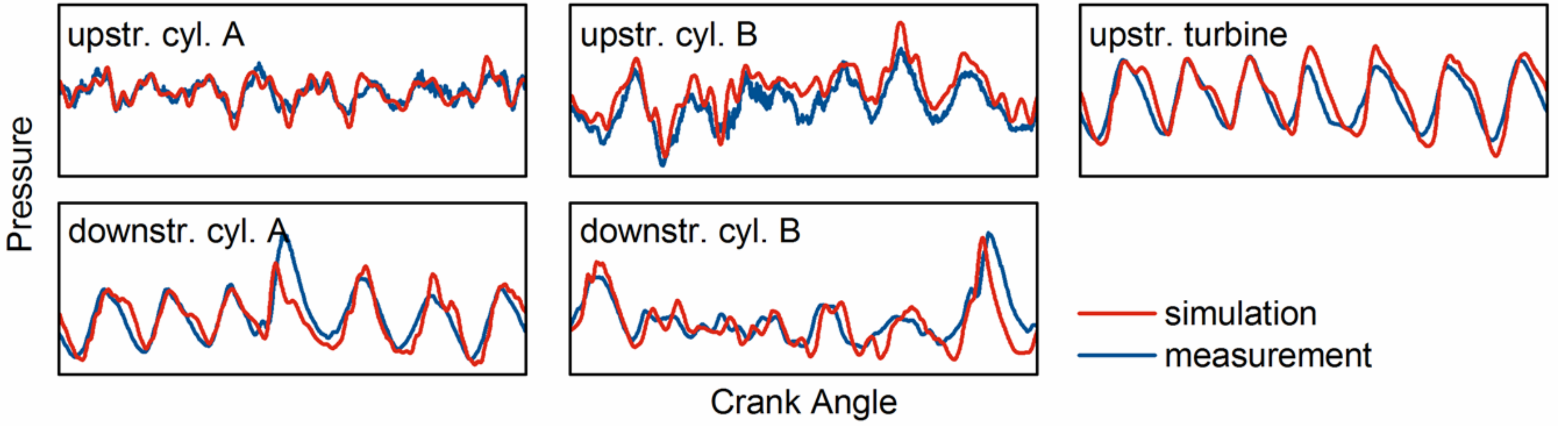
Description of the Modelling Approach

Optimization of Phenomenological Dual Fuel Combustion- and NO-Model

Implementation in full engine model:

- ☐ Very good reproduction of:
  - Low and high pressure indication
  - Air mass flow
  - Natural gas and diesel mass flow
  - IMEP and BMEP

➡ **Predictive engine model that represents the relevant engine operation map with a good precision is developed**



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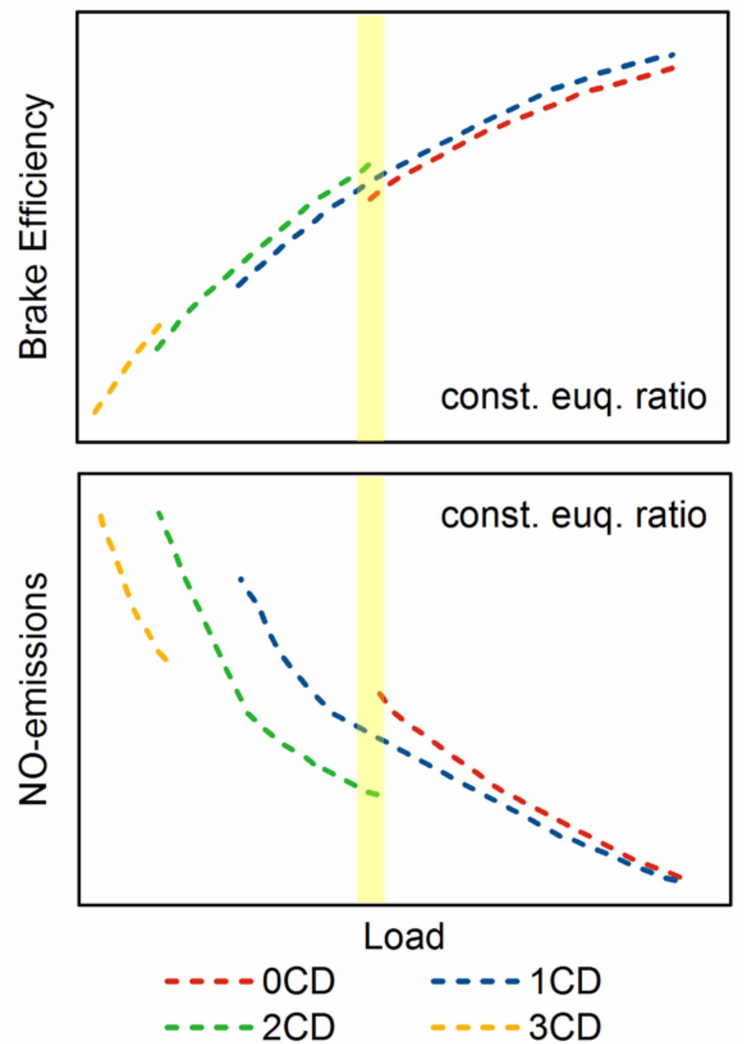
  - Engine Operation with Deactivated Cylinders
  - Effects on Efficiency and NO-emissions
- ☐ Conclusions

Cylinder Cut-out Operation

Engine Operation with Deactivated Cylinders

- ☐ Static cylinder cut-out by deactivation of gas injector for 1 - 3 cylinders in part load
- ☐ Measured equivalence ratio downstream of fired cylinders is constant
- ☐ Cylinder deactivation leads to increased efficiency and to reduced NO-emissions
- ☐ Effects rise with the number of deactivated cylinders
- ☐ Number of possible cylinders to be cut-out depends on applied load and is restricted due to the charging unit



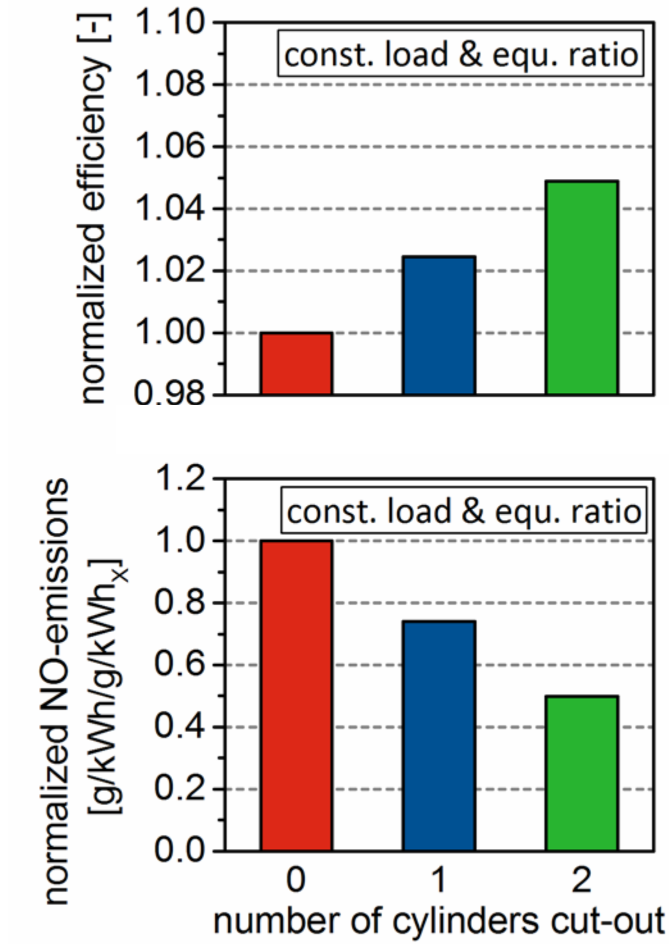
Cylinder Cut-out Operation
Engine Operation with Deactivated Cylinders

Specifications of engine operation:

- ☐ Representative engine operating point in part load
- ☐ Constant equivalence ratio of fired cylinders and load are applied

Effects of cylinder cut-out:

- ☐ Increase of efficiency by more than 4%
- ☐ Reduced NO-emissions by almost 50%
- ☐ Effects rise with the number of deactivated cylinders

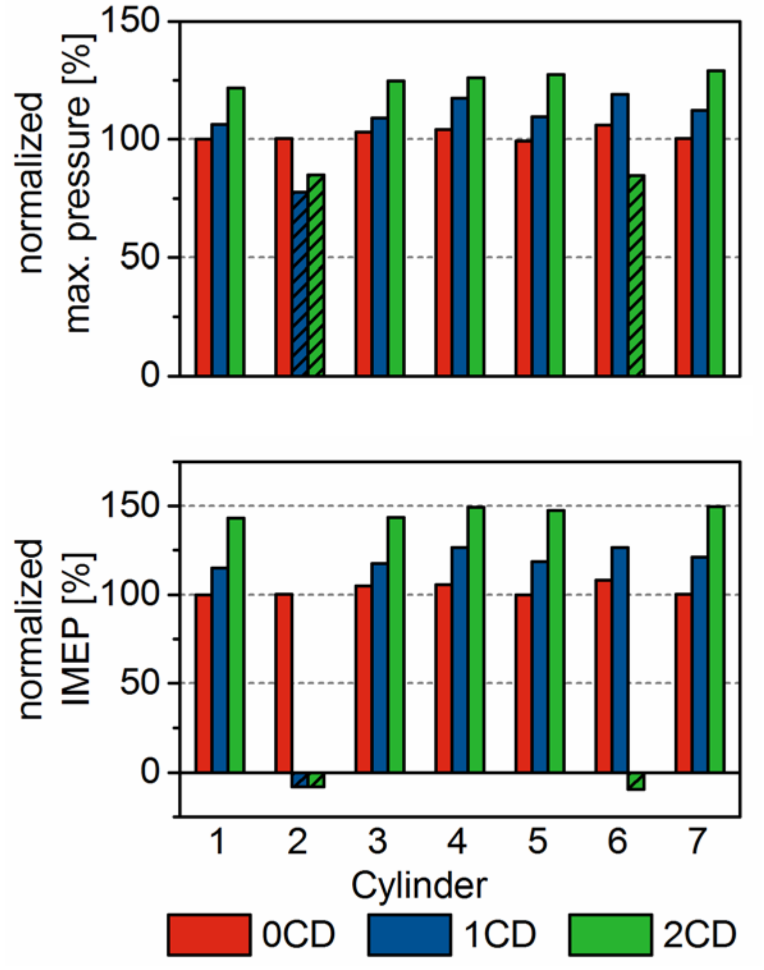


Cylinder Cut-out Operation

Engine Operation with Deactivated Cylinders

Effects on fired and cut-out cylinders:

- ☐ Applied load is distributed to the remaining fired cylinders
- ☐ Increased combustion pressure and IMEP of fired cylinders
- ☐ Air is scavenged through the deactivated cylinders; pumping work results in negative IMEP

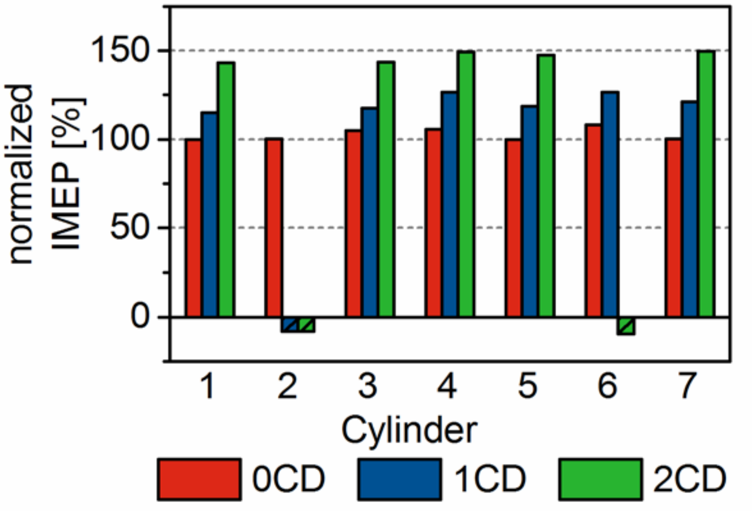


Cylinder Cut-out Operation

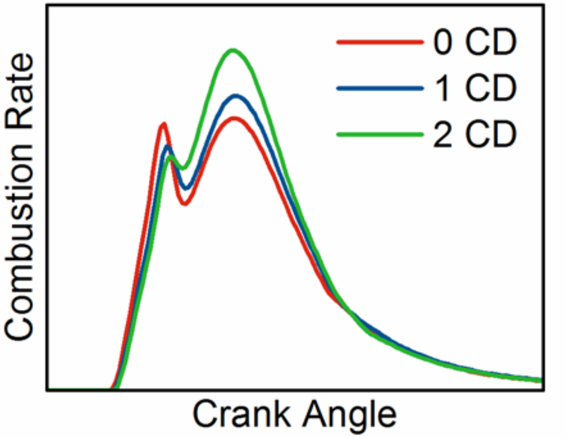
Effects on Efficiency and NO-emissions

Effect on NO-emissions:

- ☐ At low load, amount of diesel pilot is higher to ensure stable combustion
- ☐ Increased IMEP of the remaining fired cylinders leads to a reduced fraction of diesel pilot
- ☐ Combustion is shifted from a partial diesel combustion towards premixed combustion
- ☐ NO-emissions are reduced



Representative fired cylinder

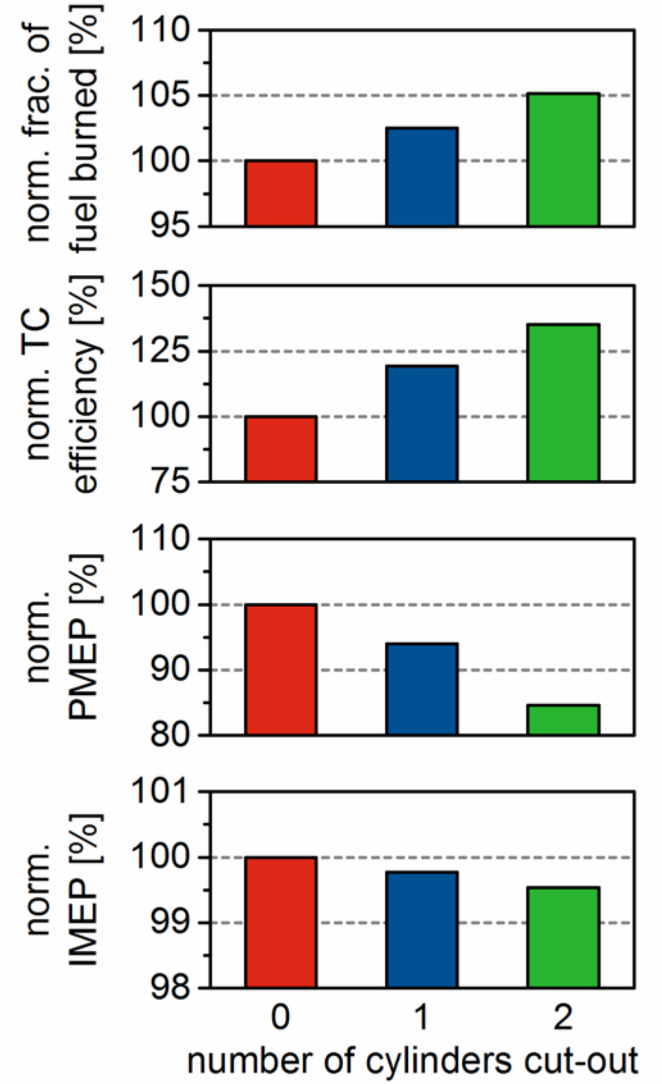


Cylinder Cut-out Operation

Effects on Efficiency and NO-emissions

Effect on efficiency:

- ☐ Increased IMEP of the remaining fired cylinders leads to:
  - Elevated fraction of burned fuel
  - Reduced fraction of wall heat loss
- ☐ Charge air pressure and turbocharger efficiency raise with numbers of cylinders cut-out. Result: increased scavenging gradient and reduced PMEP
- ☐ Distribution of applied load leads to decreased friction loss and to a reduced global IMEP



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Conclusions

- ☐ Thermodynamic and fluid mechanic engine model is developed
- ☐ Phenomenological dual fuel combustion- and NO-model is optimized
- ☐ Good correlations with test bench data are achieved
- ☐ The simulation model predicts the static cylinder cut-out:
  - Increase of the brake efficiency by more than 4%
  - Decrease of the NO emissions by nearly 50%
  - Effects rise with the number of deactivated cylinders

➡ **The presented cylinder cut-out is a valuable method to reduce the fuel expenses and minimize the environmental impact.**

Thank you for your attention!

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& Automobiltechnik

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